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TITLE: PRELIMINARY DESIGN OF THE ENERGY SYSTEM FOR THE ZTH EXPERIMENT

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SUBMITTED TO: IEEE meeting, Monterey, California, October 12-16, 1987



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# PRELIMINARY DESIGN OF THE ENERGY SYSTEM FOR THE ZTH EXPERIMENT*

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## ABSTRACT

A 4 MA reversed field pinch experiment, called ZTH, is being designed and built at Los Alamos. The first plasma discharges are scheduled to take place in FY 1991. Major electrical power equipment components, such as a pulsed generator, controlled power supplies, isolation and opening switches, current interrupters and capacitor banks are being designed and procured for this experiment. In this paper the requirements and the design philosophy of the components for the energy system are described, and a status report on the component acquisition is given.

## 1. INTRODUCTION

Los Alamos National Laboratory is designing and building the Confinement Physics Research Facility (CPRF) for the Office of Magnetic Fusion Energy of the US Department of Energy. The first experiment in the CPRF will be a 4 MA reversed field pinch device, labeled ZTH. The first plasma discharges are scheduled for FY 1991, with 4 MA experiments expected to commence in Oct. 1992. The electrical energy system for CPRF/ZTH consists of a pulsed generator, an ac distribution system, controlled power supplies for the toroidal, ohmic heating and equilibrium coils, isolation and opening switches, capacitor banks and other electrical equipment.

The experimental device will be housed in an existing 200′ × 60′ building, which has 6′ thick concrete walls and a 5′ thick concrete ceiling. A new 180′ × 60′ generator building is being constructed and a new 250′ × 65′ power supply building is in the design phase. Figure 1 shows a general facility layout. A small switch yard will be located between the generator and power supply building. Station power will be provided by a 13.4 kV, 11.5 MVA cable, which is connected to a utility transformer.

## 2. POWER AND ENERGY REQUIREMENT

The ZTH experiment is designed to produce a plasma current which rises to a value of 2 MA in 50 ms. Then the plasma current is ramped to 4 MA in 400 ms. The ramp phase is followed by a 200 ms current flat-top phase. During a plasma discharge most of the power is required by the ohmic heating coils, with a peak power requirement of 800 MW, which occurs at the end of the ramping phase. The equilibrium supplies require a total power of 60 MW and the flat-top toroidal field supply is rated at 20 MW. These power and energy requirements can not be provided by the local electric utility system. Inertial energy storage will be applied for supplying the pulsed power and energy.

## 3. PULSED GENERATOR

A cost effective way of acquiring a pulsed generator is to utilize a surplus steady-state turbo generator and to operate it in a pulsed mode. Los Alamos has acquired from an electric utility a 1430 MVA, 1800 rpm generator, which was available from a cancelled nuclear power plant. Details about the main parameters of the machine are given in Table I.

TABLE I: Generator Parameters

| | |
|---|---|
| Power rating | 1430 MVA |
| Voltage | 24 kV |
| Current | 34.4 kA |
| Synchronous speed | 1800 rpm |
| Lower speed | 1260 rpm |
| Energy at 1800 rpm | 1210 MJ |
| Extractable energy | 600 MJ |
| Pulse repetition rate | 10 min |
| Drive system rating | 8000 hp |
| Hydrogen pressure | 75 psig |
| Stator weight | 451 t |
| Rotor weight | 232 t |

Feasibility studies and tests performed by the generator manufacturer confirmed that the machine is suitable for pulsed power operation. Furthermore, the generator manufacturer assured Los Alamos that the generator, which was originally designed for hydrogen cooling, can operate safely in air. This makes the installation and operation of the machine less complex. Figure 2 depicts the projected Los Alamos generator installation. The total generator set, which is 109′ long, consists of the generator, three main bearings, the shaft driven oil pump, the turning gear, thrust bearing and the slip ring housing. To reduce the effect of the shock loading into the surrounding environment, the generator foundation will be spring mounted. Provision is made in the foundation design to install a future flywheel. During the initial operation the space provided for the flywheel is bridged by a jack shaft. An 8000 hp all solid-state, load-commutated converter drive system will accelerate the generator from standstill to full speed and also bring the generator up to synchronous speed between the load pulses. Power for the drive system and for the solid-state excitation system will be provided from the 13.4 kV utility.

## 4. AC DISTRIBUTION SYSTEM

The interface between the generator terminals and the power supply breaker has not been finalized. Different options for the interface are being investigated. In evaluating the options, methods of generator protection including the involved risk, usually caused by generator short circuit conditions, and overall costs are being considered. The options being considered include:

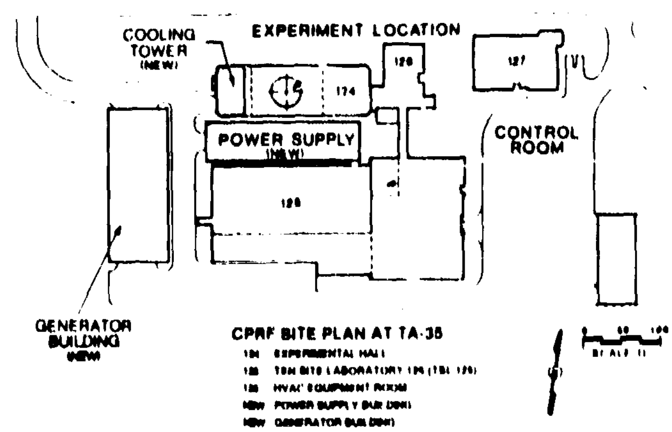


Fig. 1. CPRF site plan overview

* Work performed under the auspices of the U.S. Department of Energy.

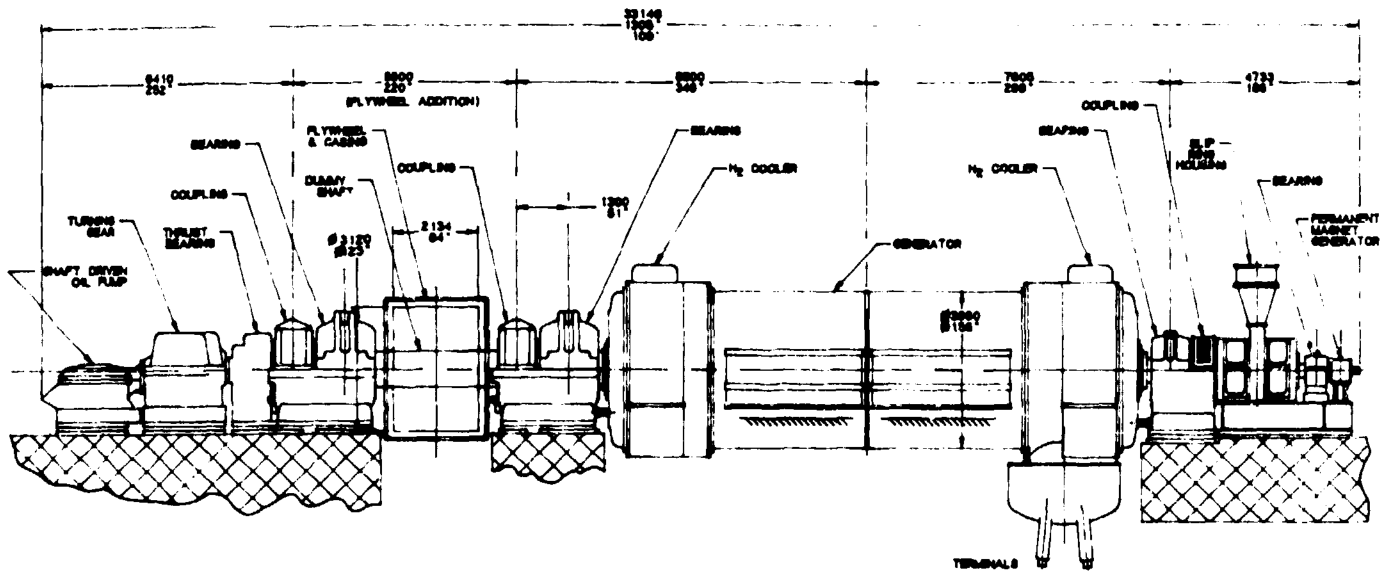


Fig. 2. Los Alamos generator installation

a) no generator breaker, no line reactor;
b) generator breaker, no line reactor;
c) line reactor, distribution type breaker;
d) line reactor, smaller generator breaker;
e) line reactor, explosive fuse.

Figure 3 shows as an example option c. Because a line reactor inhibits the voltage regulation during the current pulse, the converter cost increases with increasing line reactor value for a given converter terminal voltage and current rating. The converter cost is being taken into account for costing the ac interface.

## 5. POLOIDAL FIELD ENERGY SYSTEM -- OVERVIEW

The poloidal field energy system feeds both the ohmic heating and equilibrium coils. The main components of the poloidal energy system as shown in Fig. 4 are:

a) Four ohmic heating power supplies rated at 3840 V and 12.5 kA for 2 MA operation and 3840 V and 50 kA for 4 MA operation;
b) Sixteen equilibrium coil supplies, consisting of two sets with eight identical units, rated at 1 kV/3 kA and 1.25 kV/4 kA respectively;
c) Cold and isolation switches;
d) Four 50 kV/50 kA dc current interrupters;
e) Four 1 ohm transfer resistors.

The ohmic heating power supplies which serve both as the charging and ramp/flat-top supplies, are being installed in two phases. The first phase will provide 2 MA, the second phase 4 MA capability. During the charging mode at 2 MA converter capability, four 3840 V, 12.5 kA supplies are connected in parallel and bring the ohmic heating coil current up to 50 kA in 2.6 s. When the 4 MA converter capability is installed, the charging time is reduced to 0.45s. Before the energy transfer phase is initiated, the power supplies are bypassed and disconnected, and the coil current circulates through the bypass switch as well as the dc current interrupters. By opening the dc current interrupters, the current transfers into the 1Ω resistors. Simultaneously the equilibrium supplies are connected to the respective coils. The four main power supplies are reconnected for ramping/flat-top operation in the series mode. At the end of a plasma discharge part of the magnetic energy in the coils is converted into inertial energy by reversing the power supply output at a comfortable voltage level (0.6pu) thus avoiding converter failures.

## 6. CONVERTERS

Each of the four ohmic heating supplies can be subdivided into four six-pulse, 960 V, 12.5 kA supplies. The no-load voltage should be about 1300 V. While a 12-pulse supply shows a slight cost advantage over a 24-pulse supply, the ripple requirement during flat-top operation may require 24-pulse operation of an ohmic heating supply. This question is being studied. The addition of power supplies for 4 MA operation is achieved by adding identical ohmic heating supplies in parallel. The converter transformers will be specified as dry type units. The specifications for the converter purchase are being written.

The sixteen equilibrium coil supplies can be divided into two sets of eight each. One set requires a full load rating of 3 kA at 1 kV and the other set a full load rating of 4 kA at 1.25 kV. Because of the similarity of the supplies, one basic mechanical construction can be used.

The dry type transformer should have a 25% voltage tap and the rectifiers should have SCRs with different voltage ratings and different numbers of parallel paths. This would accomodate the 25% different voltage and current requirements with one set of supplies.

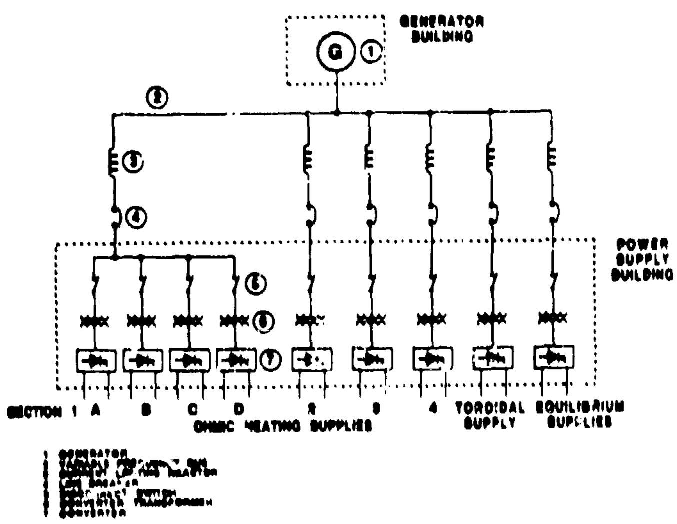


Fig. 3. ZTH power distribution system

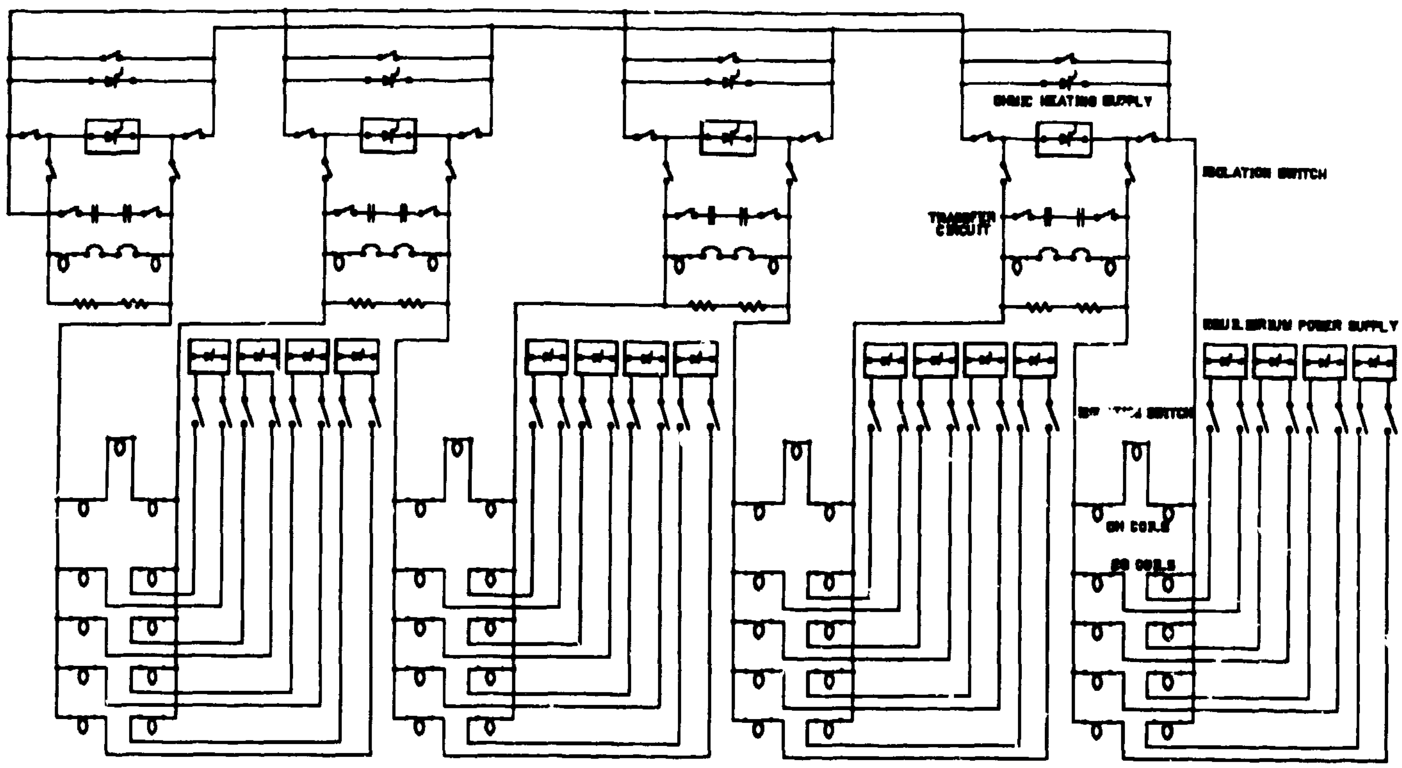


Fig. 4. Poloidal field energy system

## 7. SWITCHES

A great number (about 200) of isolation, disconnect, metal-to-metal and grounding switches are required for proper operati of the poloidal field energy system. The switch requirements, such as voltage, current, $I^2t$, closing and opening time, etc., have been determined. It is anticipated that many of the switches can be procured using commercially available ac circuit breakers, of the vacuum interrupter type. To meet some application requirements which cannot be met by a single switch, a combination of two switches will suffice. In some instances the parallel operation of a fast ignitron switch with a slower metal-to-metal switch can solve a fast closing time and high $I^2t$ requirement. Vacuum breakers of three different manufacturers are on order to be used as test switches for 25 kV, 50 kA isolation switches. The mechanical life time and current carrying capability of the ac breakers will be determined.

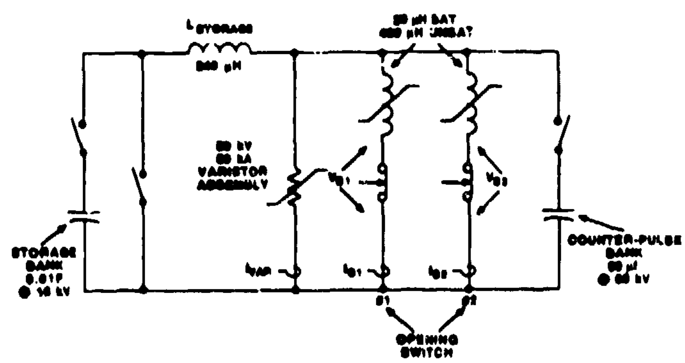


Fig. 5. Simplified electrical diagram of 50 kA, 50 kV switch te t facility

## 8. DC CURRENT INTERRUPTER

A 50 kV/50 kA DC current interrupter is at the present time not readily available at a reasonable cost from an electrical equipment manufacturer. Based on previous experience with 25 kA/25 kV breakers which were developed at Los Alamos for other US fusion experiments, we are developing the ZTH current interrupter in-house. A breaker, as shown in Fig. 5, was assembled and tested. Major components were: six vacuum bottles in a 2 parallel/3 series arrangement; 90µF, 60 kV counterpulse bank; saturable reactors; MOV transfer resistor. The load current is provided by a 10,000 µF, 10 kV capacitor bank in series with a 240 µH inductor. The vacuum bottles are of the axial magnetic field type.

To this date over 100 interruptions at 50 kV/50 kA and 12 at 55 kV/55 kA have been accomplished with 100% breaker reliability, however, limited test facility reliability. A successful 56 kA/54 kV current interruption is shown in Fig. 6. We are designing a new switch test facility to do switch life testing (2,000 shots) with the rated $I^2t$ requirement. In addition, the test facility will incorporate all the switch support systems such as control and data acquisition systems, ignitron switches, etc., which are needed for ZTH. Also, these auxiliary systems are being tested. Recently, we learned that a higher current carrying vacuum interrupter is available at a reasonable price from a different manufacturer. These bottles and the actuator have been ordered and will be tested in the new facility. These higher current bottles may reduce the number of parallel bottles from two to one.

## 9. TRANSFER RESISTOR

A stainless steel, water cooled, linear resistor is our first choice as transfer resistor. However, work is proceeding on a non-linear, metal oxide varistor based transfer resistor. A non-linear resistor would increase the transfer efficiency for ZTH. Tests are being conducted to determine a safe energy absorption limit for MOVs. Discs of two different manufacturers are being tested, some of the discs to destruction.

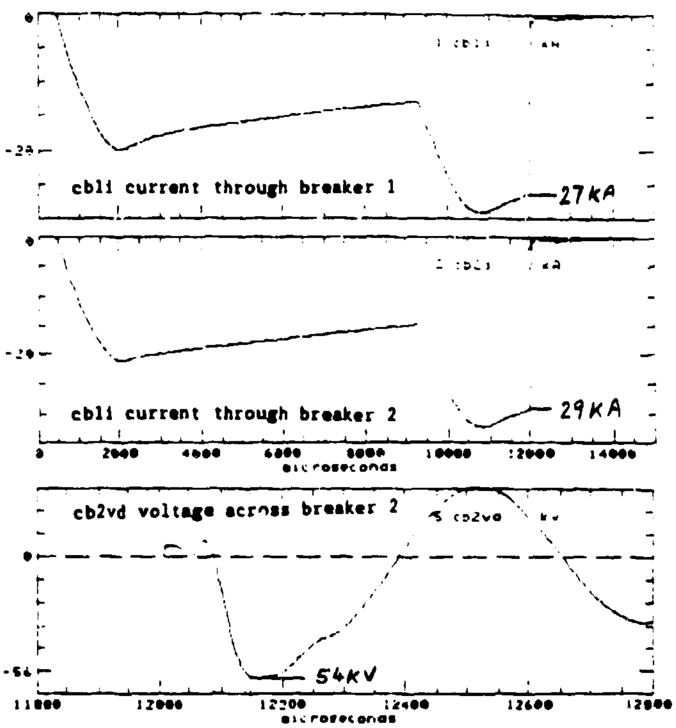


Fig. 6. Current and voltage traces for a 56 kA, 54 kV dc current interruption

## 10. TOROIDAL FIELD ENERGY SYSTEM

The ZTH toroidal field energy system is in the preliminary design phase. The bias toroidal magnetic field for the RFP experiment will be established by discharging a capacitor bank into the toroidal field coils. The capacitor bank will be allowed to ring during plasma current build-up to aid the reversal of the toroidal magnetic field at the wall. During plasma current flat-top phase, the current in the TF coils will be sustained by thyristor converter power supplies. Figure 7 shows representative current waveshapes and power supply requirements.

The technical design criteria for ZTH specifies that the initial bias toroidal field before the plasma current rise will be a maximum of 0.3 Tesla, and that it should be possible to reverse this field to about F = -0.5 in a reversal time that is continuously variable from 0.5 to 50 ms. The specification was adopted after careful consideration of the volt-second consumption of various RFP devices. The best way to achieve 2 MA plasma operation with limited volt-seconds available will be to operate in the fast reversal mode, in which toroidal field reversal occurs early in the 50 ms plasma current rise time. This specification permits design of ZTH with a smaller toroidal field capacitor bank than is customarily used. The smaller bank, however, commits ZTH to operate in the fast reversal mode to reach 2 MA plasma current, because 0.3 Tesla initial toroidal field is consistent with operation in matched mode only to about 0.8 MA plasma current. Matched mode operation to 2 MA could be achieved by increasing the size of the TF capacitor bank.

The TF circuit is required to produce a wide continuous range of reversal times. To achieve this will require that the TF capacitor bank be modular in arrangement and that the TF coil connection scheme be capable of many series/parallel combinations. It will also be necessary to trim the reversal time by changing the number of capacitors within a capacitor module.

The TF coils are connected in 24 sets of two series coils each. The capacitor bank is subdivided into 48 modules, each consisting of ten 170 uF 10 kV capacitors with associated discharge and crowbar ignitrons, mechanical by-pass switches, damping resistors, dump switches, etc. Total bank energy is 4.08 MJ. To accomplish the required switching and reversal of current in the switches will require a total of 192 ignitrons, in inverse parallel connections to allow current commutation. However, other alternatives such as diodes, thyristors, etc. are being investigated and may eventually be used for nominal and/or special situations.

To flat-top the current in the TF coils for 2 MA plasma current requires a 6 MW power supply. When all of the TF coils are connected in series, this power must be supplied at 1000 volts and 6000 amps. To provide the proper coil current to ramp the plasma current from 2 MA to 4 MA will require increasing the power supply output current from 6 kA to 20 kA. The voltage rating remains about the same at 1 kV. The entire toroidal field energy system is being designed so that the power supply upgrade is the only change required to add the capability to ramp to 4 MA.

## 11. SUMMARY

The CPRF/ZTH experiment is being designed and constructed for a 4 MA plasma current. Major components of the electrical energy system such as the pulsed generator, the ac distribution system, power supplies, isolation and opening switches and capacitor banks are being designed and procured. The pulsed generator has been acquired and all the auxiliary components have been shipped to Los Alamos. The transportation contract for hauling the stator and rotor to Los Alamos has been awarded. The specifications for the power supplies are being determined. A 50 kV/50 kA dc current interrupter has been successfully tested. Isolation switches are being procured for testing. MOV devices are being tested to determine their suitability for transfer resistor application.

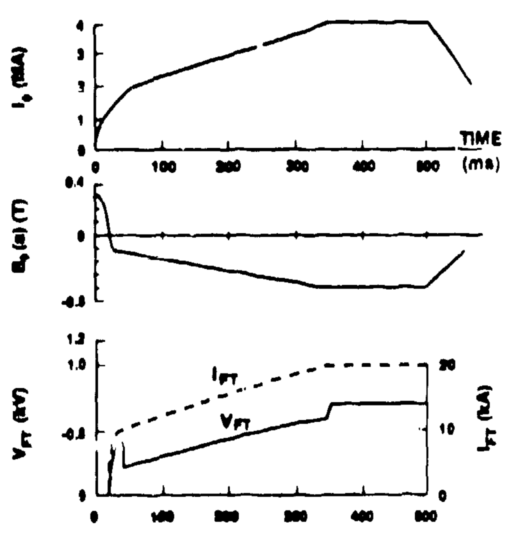


Fig. 7. Required magnetic field waveshapes and toroidal field power supply requirements